

NONVOLATILE DATA STORAGE CIRCUIT USING FERROELECTRIC  
CAPACITORS

CROSS-REFERENCE TO RELATED APPLICATIONS

5           This application is based upon and claims the benefit  
of priority from the prior Japanese Patent Application No.  
2002-247347, filed on August 27, 2002, the entire contents  
of which are incorporated herein by reference.

10                           BACKGROUND OF THE INVENTION

1.   Field of the Invention

          This invention relates to a nonvolatile data storage  
circuit using ferroelectric capacitors, and in particular,  
to a nonvolatile data storage circuit capable of stabilizing  
15   storage operation when the power supply is off.

2.   Description of the Related Art

          One type of data storage circuit capable of high-speed  
operation is a latch circuit in which a pair of inverter  
20   inputs and outputs are cross-connected. Latch circuits are  
used as element circuits in flip-flops, or are used as SRAM  
memory cells. A latch circuit is itself a volatile data  
storage circuit, in which the held data is lost when the  
power supply falls. Therefore, nonvolatile data storage  
25   circuits have been proposed.

          As a nonvolatile data storage circuit, in the non-  
patent document 1 described below, a device in which

ferroelectric capacitors are connected as variable-capacitance capacitors to the storage nodes of a latch circuit forming an SRAM memory cell. Fig. 1 is a circuit diagram of the memory cell. This memory cell comprises a latch circuit 2 in which the input and output terminals of CMOS inverters 1a, 1b are cross-connected; transfer gates 4a, 4b whose gates are connected to the word line WL and either sources or drains are connected to bit lines BL, BLX; and ferroelectric capacitors FC1, FC2 connected to the pair of storage nodes N, NX of the latch circuit 2. The electrodes on the opposite sides of the ferroelectric capacitors FC1, FC2 are connected to the plate line PL.

In the latch circuit 2 comprising the pair of inverters, data is lost when the power supply is interrupted. However, by connecting the ferroelectric capacitors FC1, FC2 to the pair of storage nodes N, NX, the polarization direction of the ferroelectric films in the ferroelectric capacitors can be controlled according to the voltage levels of the storage nodes, and this polarization direction is maintained as a residual polarization even after the power supply falls.

For example, if node N is at L level and node NX is at H level, when the plate line PL is at L level, a voltage is applied to the ferroelectric capacitor FC2, and the polarization direction becomes the direction of the arrow. When the plate line PL is driven to H level, a voltage is applied in the reverse direction to the ferroelectric capacitor FC1, and the polarization direction becomes the

opposite direction. This polarization direction is maintained even if the power supply falls, due to the hysteresis characteristic of the ferroelectric film. The above operation associated with the plate line is called a  
5 store operation.

When the power supply is turned on, the power supply voltage VDD gradually rises; but due to differences in the polarization direction, the capacitances of the ferroelectric capacitors as seen from nodes N and NX are  
10 such that  $FC1 > FC2$ . Consequently the rise in voltage levels at the nodes N and NX due to currents flowing via the p-channel transistors of the inverters 1a and 1b, accompanying the rise of the power supply voltage VDD, is slower on the side of the capacitor FC1 with larger capacitance, and  
15 faster on the side of the capacitor FC2 with smaller capacitance. As a result, a voltage difference is created between the nodes N and NX, and through the amplification action of the latch circuit 2, the L level and H level of the nodes N and NX prior to power supply interruption are  
20 restored. This operation is called "recall operation".

Non-patent reference 1: T. Miwa et al, "A 512 kbit low-voltage NV-SRAM with the size of a conventional SRAM," 2001 Symposium on VLSI Circuits, Digest of Technical Papers.

In the nonvolatile data holding circuit shown in Fig. 1,  
25 when the power supply voltage VDD is lower level, the transistor leakage currents of the inverters 1a and 1b cause the ferroelectric capacitors FC1 and FC2 to be charged.

Hence the voltages at the nodes N and NX are determined by the charging leakage currents and by the capacitances of the ferroelectric capacitors FC1 and FC2. Here a leakage current charging a capacitor is the difference between the p-channel transistor leakage current and the n-channel leakage current.  
5 This transistor leakage current differs greatly due to distribution in threshold voltages. For example, when the threshold voltage scattering is  $\Delta V_{th}=80$  mV, the leakage current is different by nearly one order.

10 Hence depending on scattering in the threshold voltages of the transistors comprised by the latch circuit, the H level and L level may be inverted in the recall operation. Scattering in threshold voltages depends on device fabrication processes, and cannot easily be reduced.

15 In order to resolve this problem, the applicant previously submitted patent applications, proposing improved nonvolatile data holding circuits using ferroelectric capacitors. One such example is Japanese Patent Laid-open No. 13-400507 (filed December 28, 2001). In this improved  
20 version, a transistor for activation is provided on the power supply side of the latch circuit, and in recall operation, initially the plate line PL is driven, voltages are generated at the pair of storage nodes of the latch circuit according to the polarization directions of the  
25 ferroelectric capacitors, and thereafter the activation transistor is driven to activate the latch circuit, the voltage difference between the storage nodes is amplified,

and the original data is latched.

In this improved version, a pair of ferroelectric capacitors are connected to each of the storage nodes of the latch circuit, two plate lines are driven to store data when  
5 interrupting the power supply, and when the power supply is turned on, one of the plate lines is driven to recall the data. The difference in capacitances of the pair of ferroelectric capacitors can be utilized to generate a large voltage difference between the storage nodes of the latch  
10 circuit through the recall operation.

However, in this improved version, when the two plate lines are driven in the store operation, coupling noise between the ferroelectric capacitors may cause the levels of the pair of storage nodes of the latch circuit to be  
15 inverted. Transistor connection capacitances, wiring capacitances, and other parasitic capacitances are connected to the storage nodes; but the capacitances of the ferroelectric capacitors are extremely large compared with these parasitic capacitances. Hence the effect of the above  
20 coupling noise is great, and consequently the storage node levels fluctuate considerably so that the data of the latch circuit may be inverted, and failure in writing data to the ferroelectric capacitors may occur.

The above problems are prominent when the size of  
25 transistors in the latch circuit is decreased and the current driving capacity is reduced in order to raise integration densities, and when there exists an imbalance in

the performance of the inverters of the latch circuit or an imbalance in the parasitic capacitances of the storage nodes.

#### SUMMARY OF THE INVENTION

5           Hence an object of this invention is to provide a nonvolatile data storage circuit using ferroelectric capacitors which operates stably.

          A further object of this invention is to provide a nonvolatile data storage circuit using ferroelectric  
10          capacitors, the storage operation of which is stabilized.

          A further object of this invention is to provide a nonvolatile data storage circuit using ferroelectric capacitors, which enables rewriting during recall.

          In order to achieve the above objects, in a first  
15          aspect of this invention, a nonvolatile data storage circuit has a data holding circuit having a storage node, and a plurality of ferroelectric capacitors one electrodes of which are connected to the storage node. In this nonvolatile data storage circuit, in store operations to write the data  
20          of the data holding circuit to the ferroelectric capacitors, the timing of at least the rising or the falling of plate signals supplied to the other electrodes of the plurality of ferroelectric capacitors, is made different.

          In the above first aspect, during store operation, the  
25          timing of the plate signals applied to the plurality of ferroelectric capacitors connected to the storage node is shifted, so that coupling noise between the ferroelectric

capacitors is dispersed and can be reduced, and data inversion of the data holding circuit can be prevented.

In a preferred embodiment of the above invention, the timing of the falling edge of a first plate signal and of the rising edge of a second plate signal, applied to two ferroelectric capacitors, is made coincident. That is, the first plate signal is applied initially, and the second plate signal is made to rise with the same timing as the falling edge of the first plate signal. By this means, the phases of the coupling noise between the two capacitors are inverted and the noise is canceled, so that data inversion can be prevented.

In order to achieve the above objects, in a second aspect of this invention, a nonvolatile data storage circuit has a data holding circuit having a storage node, and a pair of ferroelectric capacitors one electrode of each of which is connected to the storage node. In the nonvolatile data storage circuit, during recall operation to rewrite to the data holding circuit the data of the ferroelectric capacitors, the timing of the plate signals supplied to the other electrodes of the pair of ferroelectric capacitors is shifted, the data holding circuit is activated so that data is latched when a first plate signal is applied, and subsequently a second plate signal is applied.

In the above second aspect, a voltage is generated at the storage node due to application of the first plate signal, and at this time the data holding circuit is

activated and data is restored. At this time, data is rewritten to the first ferroelectric capacitor. Then, by applying the second plate signal, data is also rewritten to the second ferroelectric capacitor.

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#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a circuit diagram of a conventional memory cell using ferroelectric capacitors;

Fig. 2 is a circuit diagram of a nonvolatile flip-flop circuit disclosed in a previous patent application  
10 specification;

Fig. 3 is a circuit diagram of another nonvolatile flip-flop circuit disclosed in a previous patent application specification;

Fig. 4 is an operation waveform diagram of the  
15 nonvolatile flip-flop circuit of Fig. 3;

Fig. 5 is a diagram showing the polarization direction in a ferroelectric capacitor;

Fig. 6 is an equivalent circuit diagram of the capacitance connected to the storage node pair N, NX;

20 Fig. 7 is a diagram which explains problems with Fig. 3 and Fig. 4;

Fig. 8 is a circuit diagram of a nonvolatile flip-flop circuit of this aspect;

Fig. 9 is a waveform diagram showing a first example of  
25 a plate signal in this aspect;

Fig. 10 is a plate signal generator circuit diagram to generate a first waveform example;



Fig. 11 is another plate signal generator circuit diagram to generate a first waveform example;

Fig. 12 is a waveform diagram showing a second example of a plate signal of this aspect;

5 Fig. 13 is a plate signal generator circuit diagram to generate a second waveform example;

Fig. 14 is a waveform diagram showing a third example of a plate signal of this aspect;

10 Fig. 15 is a plate signal generator circuit diagram to generate a third waveform example;

Fig. 16 is a diagram showing a modified example of a nonvolatile latch circuit of this aspect; and,

Fig. 17 is a diagram showing a memory circuit of this aspect.

15 DESCRIPTION OF THE PREFERRED EMBODIMENTS

Below, aspects of this invention are explained, referring to the drawings. However, the scope of protection of this invention is not limited to the following aspects, but extends to the inventions described in the Scope of  
20 Claims and to inventions equivalent thereto.

Fig. 2 is a circuit diagram of a nonvolatile flip-flop circuit disclosed in the above-mentioned preceding patent application specification. This flip-flop is a D-type flip-flop comprising a former-stage master latch circuit 10 and a  
25 latter-stage slave latch circuit 12. The master latch circuit 10 comprises a pair of inverters 13, 14 and transfer gates 15, 16; the input data Din is input when the clock CK

is at L level, and this is latched when the clock CK is at H level. The slave latch circuit 12 also comprises a pair of inverters 1a, 1b and transfer gates 17, 18; when the clock CK is at H level, the output of the master latch circuit is input, and this is latched when the clock CK is at L level. The data held by the slave latch circuit 12 is output as the output data Dout.

In the example of Fig. 2, the ferroelectric capacitors FC1, FC2 are respectively connected to the pair of storage nodes N, NX of the slave latch circuit 12, and the plate signal PL is applied to the opposite-side electrodes of the capacitors. Also, activation transistors PT1, NT1 are provided on the high-power-supply side and the low-power-supply side, respectively, of the inverters 1a, 1b of the slave latch circuit 12, and the activation signals EN, ENX are applied to the gates of these activation transistors. Hence in the flip-flop of Fig. 2, the data held by the slave latch circuit is held by the capacitors FC1, FC2 even when the power supply is turned off.

The store operation of the slave latch circuit before the power supply falls is the same as in the conventional example; if the latch circuit maintains the L level and H level at the storage node pair N, NX respectively, then the plate signal PL changes from L level to H level and then to L level, and polarization states indicated by the arrows occur in the ferroelectric capacitors FC1, FC2. The recall operation when the power supply is turned on differs from

the conventional example; the plate signal PL is driven from L level to H level, a voltage difference is generated between the storage nodes N, NX of the latch circuit according to the polarization states, and thereafter, when the activation signals EN, ENX are driven to the H level and L level respectively, the latch circuit 12 is activated, the voltage difference between the storage node pair is amplified, and the original data is latched.

In the nonvolatile latch circuit of Fig. 2, a voltage difference is generated between the storage node pair N, NX by the difference in capacitance values of the ferroelectric capacitors FC1, FC2. However, a sufficient voltage difference cannot be generated solely by the difference in capacitances of the two capacitors. Hence a plurality of ferroelectric capacitors are connected to the storage node pair, and during recall operation a larger voltage difference is generated between the storage node pair.

Fig. 3 is a circuit diagram of another nonvolatile flip-flop circuit disclosed in the preceding patent application specification; as described above, pairs of ferroelectric capacitors FC1, FC3 and FC2, FC4 are connected to the respective storage nodes N and NX. A first plate line PL1 and second plate line PL2 are connected to the opposite-side electrodes of these capacitors.

Fig. 4 is an operation waveform diagram of the nonvolatile flip-flop of Fig. 3. Fig. 5 is a diagram showing the polarization direction of a ferroelectric capacitor, and

Fig. 6 is an equivalent circuit diagram of the capacitances connected to the storage node pair N, NX. The operation of the nonvolatile flip-flop is explained referring to these drawings.

5            Suppose that the latch circuit 12 is in a state in which node N is at L level and node NX is at H level. In this state, a store operation is performed before the power supply is turned off. As shown in Fig. 4, the first and second plate signals PL1, PL2 are raised simultaneously from  
10   L level (ground voltage) to H level (power supply voltage), and then again set at L level. When both plate signals are at L level, a negative-direction voltage is applied to the ferroelectric capacitors FC2 and FC4, the ferroelectric films of the capacitors FC2, FC4 move to point A on the  
15   hysteresis curve, and polarization in the direction of the arrow occurs. Thereafter, when the plate signals PL1 and PL2 are sent to H level, the voltage applied to the ferroelectric capacitors FC2 and FC4 vanishes, and the capacitors FC2, FC4 move to point B. On the other hand, a  
20   positive-direction voltage is applied to the ferroelectric capacitors FC1 and FC3, the capacitors FC1, FC3 move to point C, and polarization occurs in the direction of the arrow opposite that of FC2 and FC4. Then, when the plate signals PL1 and PL2 are sent to L level, the capacitors FC1  
25   and FC3 move to point D, and the capacitors FC2 and FC4 move to point A.

By this means, the data of the latch circuit 12 is held

by the four ferroelectric capacitors. Thereafter, when the power supply is interrupted, the voltage levels at the storage node pair N, NX of the latch circuit 12 disappear, and the capacitors FC2 and FC4 move to point B. Upon  
5 interruption of the power supply the data held by the latch circuit disappears, but remains as a residual polarization in the ferroelectric capacitors, so that the data is maintained.

Next, when the power supply is turned on, as the power  
10 supply voltage VDD rises, the activation signal ENX controlled to H level also rises. Thus the activation signal EN is controlled to L level and the signal ENX which is the inversion of same is controlled to H level, and the latch circuit 12 enters an unactivated state. When the first plate  
15 signal PL1 is driven from L level to H level, a voltage with the same direction as during storing is applied to the ferroelectric capacitors FC1 and FC2, and a voltage in the direction opposite that during storing is applied to the ferroelectric capacitors FC3 and FC4. In other words, when  
20 the first plate signal PL1 goes to H level, the ferroelectric capacitors FC1 and FC2 move to point C from D and B on the hysteresis curve, and the ferroelectric capacitors FC3 and FC4 move to point A from D and B. The charge amount Q for the same applied voltage V is different  
25 for each capacitor, so that the capacitances C of the capacitors are, from  $C=Q/V$ , such that  $FC1 < FC3$  and  $FC2 > FC4$ . If small capacitances are 50 fF, large capacitances are

200 fF, and the parasitic capacitances at the storage nodes N, NX are 5 fF, then the equivalent circuit is as shown in Fig. 6.

5 The voltages  $V_n$ ,  $V_{nx}$  at the storage nodes N, NX when the first plate signal PL1 goes to H level (3.3 V) are, from division of the capacitances connected to each of the nodes,

$$V_n = 3.3V \times (50fF / (5fF + 50fF + 200fF)) = 0.65V$$

$$V_{nx} = 3.3V \times (200fF / (5fF + 50fF + 200fF)) = 2.59V$$

10 By connecting one pair of ferroelectric capacitors to each of the storage nodes N and NX, and utilizing the relations  $FC1 < FC3$  and  $FC2 > FC4$  during the recall operation, a larger voltage difference can be generated between the storage nodes. In this state, when the activation signals EN and ENX of the latch circuit are  
15 driven to H level and L level respectively, the latch circuit 12 is activated, the voltage difference between the storage node pair is amplified, and the original data can be reliably latched.

Fig. 7 explains the problems of Fig. 3 and Fig. 4. As  
20 shown in Fig. 6, comparing with the parasitic capacitance 5 fF at the storage nodes N, NX, the capacitance values of the ferroelectric capacitors FC1 to FC4 are quite large. Hence during store operations, when the plate signals PL1 and PL2 rise from L level to H level, and when they fall from H  
25 level to L level, coupling noise is superimposed at the storage nodes N and NX.

In Fig. 7, at the time when the first and second plate

signals PL1, PL2 rise, the nodes NX, N rise together through coupling, and the voltage difference  $dV1$  at the regular state changes to  $dV2$ . Also, at the time when the plate signals falls, the nodes NX, N fall together so that the voltage difference is reduced to  $dV3$ . This example is a waveform which appears when, for example, the driving ability of the p-channel transistor of the inverter 1a driving the node NX is small, and the driving ability of the n-channel transistor of the inverter 1b driving the node N is large. Also, this waveform appears when the parasitic capacitance of the node NX is small and the parasitic capacitance of the node N is large.

In other words, the coupling noise by the rising edge of the plate signal is absorbed by the operation of the latch circuit 12, and the action tends to maintain the storage nodes N, NX in the L and H level states. However, when the driving ability of the p-channel transistor of the inverter 1a is weak, and the driving ability of the n-channel transistor of the inverter 1b is large, the level of the node NX driven to the H-level side by the p-channel transistor of the inverter 1a is greatly affected by the coupling noise so that the voltage fluctuation thereof is increased. On the other hand, at the node N with the L-level side driven by the n-channel transistor of the inverter 1b the coupling noise is absorbed, so that the voltage fluctuation is smaller. Consequently the voltage difference  $dV3$  between the two storage nodes becomes extremely small at

the falling edge of the plate signals PL1, PL2. In the worst case, as shown in Fig. 7B, the voltage levels of the storage node pair may be inverted. This results in failure of the store operation.

5           When characteristic scattering is opposite of the above occurs, that is, when the driving ability of the p-channel transistor of the inverter 1a is large and the driving ability of the n-channel transistor of the inverter 1b is small, then there is the danger of occurrence of data  
10 inversion at the rising edges of the plate signals PL1 and PL2 in Fig. 7A. That is, coupling noise causes the voltage at node N to rise higher and the voltage at node NX to not rise much, so that the voltage difference  $dV_2$  becomes extremely small.

15           The above data inversion problem occurs similarly when there is imbalance in the parasitic capacitances of the storage nodes of the latch circuit. In ordinary latch circuits, the capacitances of the inverter and node pair may be formed with an imbalance such that latch inversion  
20 readily occurs. In the case of such a latch circuit, the above problem becomes serious. In addition, manufacturing variability may also give rise to imbalance in inverter capacities.

Fig. 8 is a circuit diagram of a nonvolatile flip-flop  
25 of this embodiment. The same citation numbers as in Fig. 3 are assigned; the flip-flop comprises a master latch circuit 10 and slave latch circuit 12; the master latch circuit 10



has inverters 13 and 14, and the slave latch circuit 12 has inverters 1a and 1b. Fig. 8 shows the specific CMOS inverter circuit of the inverters 1a and 1b. For the p-channel transistors of these inverters, the power supply VDD is  
5 connected to the substrate (n-type semiconductor), and for the n-channel transistors, the ground voltage VSS is connected to the substrate (p-type substrate). These transistors are connected to the power supply VDD and ground VSS via the activation transistors PT1 and NT1.

10 In the nonvolatile flip-flop of Fig. 8, the slave latch circuit 12 has ferroelectric capacitors FC1 to FC4, so as to be a nonvolatile latch circuit. First and second plate signals PL1 and PL2 supplied to these ferroelectric capacitors are generated by the plate signal generator  
15 circuit 20. In this embodiment, the timing of the first and second plate signals PL1 and PL2 generated by this plate signal generator circuit 20 differs from the example of Fig. 7.

Fig. 9 is a waveform diagram showing a first example of  
20 a plate signal of this aspect. Fig. 9 shows the first and second plate signals PL1 and PL2 in the store operation when the power supply is turned off, as well as the waveforms of the storage node pair N and NX of the latch circuit. In the first example, the first plate signal PL1 rises at time t1,  
25 and then, after a prescribed time has elapsed, the second plate signal PL2 rises at time t2. Then, at time t3 the first plate signal PL1 falls, and subsequently at time t4

the second plate signal PL2 falls.

In this way, by shifting the timing of the rising and falling of the first and second plate signals PL1, PL2, the coupling noise accompanying driving of the two plate signals is no longer superimposed, and the coupling noise is dispersed. Hence the magnitude of the coupling noise at the times  $t_1$  to  $t_4$  can be reduced, and as a result the voltage fluctuation at the storage nodes N, NX can be reduced. Consequently, as shown in Fig. 9, the operating margins at times  $t_3$  and  $t_4$  are increased, and inversion of the voltage levels at the storage nodes due to coupling noise does not readily occur. In this example, it is assumed that the driving ability of the p-channel transistor of the inverter 1a is small, and that the driving ability of the n-channel transistor of the inverter 1b is large. In the converse case also, however, the timing of plate signal rising is shifted at times  $t_1$  and  $t_2$ , and so the operating margin under these conditions is also increased.

In the first example, the rise and fall timing of the first and second plate signals should be respectively shifted. Hence for example, initially the first plate signal PL1 rises, and after the second plate signal PL2 then rises the second plate signal PL2 may fall, followed by the fall of the first plate signal PL1. Or, the order of the first and second plate signals may be reversed. In any case, by dispersing the coupling operation due to the ferroelectric capacitors accompanying the plate signal driving, data

inversion of the latch circuit can be suppressed.

Fig. 10 is a circuit diagram of the plate signal generator circuit which generates the first waveform example. This plate signal generator circuit 20 has a control signal generator circuit 22 which generates control signals 22A, 22B in response to the store signal STORE and recall signal RECALL; inverters 24, 25 which shape the waveforms of the plate signals PL; AND gates 26, 27 which output the plate signals PL according to the control signals 22A, 22B; and a delay chain circuit 28 comprising inverters in a plurality of stages.

As shown in Fig. 4, the plate signal generator circuit 20 of Fig. 10 generates first and second plate signals PL1 and PL2 in the store operation, and generates only a first plate signal PL1 in the recall operation. Further, by providing a delay chain circuit 28 in the propagation route of the second plate signal, the timing of both the rising and falling of the second plate signal PL2 can be delayed beyond those of the first plate signal PL1, as in Fig. 9.

Fig. 11 is a circuit diagram of another plate signal generator which generates the first waveform example. In this example, in place of the delay chain circuit 28 of Fig. 10, an inverter 30, delay capacitor 33, Schmitt trigger 31, and inverter 32 are provided. The Schmitt trigger is a gate with a comparatively high inversion threshold voltage during rising input, and a comparatively low inversion threshold voltage during falling input and its voltage gain is very

high since it utilizes the positive feedback. The delay capacitor 33 causes the rising and falling of the propagating signal to become gradual, and the Schmitt trigger 31 applies a delay time to the second plate signal PL2 according to the rising and falling slopes. Hence the waveforms of the generated first and second plate signals become the same as in Fig. 9. However, in Fig. 11 numerous inverter stages for a delay chain 28 is not necessary, and so the circuit scale can be reduced.

Fig. 12 is a waveform diagram showing a second example of a plate signal in this aspect. In this example, the timing of the falling of the first plate signal PL1 and the rising of the second plate signal PL2 substantially coincide. As a result, at time  $t_2$  the coupling noise direction accompanying driving of both plate signals PL1 and PL2 is reversed, and noise is canceled. At times  $t_1$  and  $t_3$ , only a single plate signal performs driving, so that the coupling noise is reduced and the operation margin is increased. In the example of Fig. 12, the pulse width  $W_1$  and delay amount  $D_1$  of the first plate signal and second plate signal are equal, so that both plate signals PL1, PL2 are generated from a common pulse signal, and the timing of the falling of the first plate signal PL1 is made to coincide with the timing of the rising of the second plate signal PL2.

Here, to make the timing of the above rising and falling "substantially coincide" means that there is coincidence to the extent that there is overlap of at least

a portion of the interval of the rising of one signal and the interval of the falling of the other signal.

Fig. 13 is a circuit diagram of the plate signal generator to generate the second waveform example. In this circuit, a pulse signal 36A with the same pulse width as the delay time D1 is generated from the common plate signal PL by the delay circuit 34, inverter 35, and AND gate 36. Based on this signal 36A, the first and second plate signals PL1, PL2 are generated. And, the same delay circuit 34 is provided in the propagation route of the second plate signal PL2, so that the second plate signal PL2 is delayed by the delay time D1 compared with the first plate signal PL1. As a result, as shown in Fig. 12, the two plate signals PL1 and PL2 have the same pulse width ( $W1=D1$ ), and the PL2 waveform is delayed by one pulse width. Consequently the timing of the falling edge of the first plate signal PL1 and the rising edge of the second plate signal PL2 match.

Fig. 14 is a waveform diagram showing a third example of a plate signal of this aspect. In Fig. 14, similarly to Fig. 4, the store operation before the power supply is turned off and the recall operation after the power supply is turned on are shown. What is different from Fig. 4 is that, during the store operation, the fall timing of one of the two plate signals PL1 and PL2 and the rise timing of the other coincide, and that, during recall, after driving the first plate signal PL1, the second plate signal PL2 is also driven. More exactly, the relation between the two plate

signals is the same during the store operation and during the recall operation.

In the store operation, the rise timing of the first plate signal PL1 and second plate signal PL2 is shifted, and the fall timing is also shifted. Further, the fall timing of the first plate signal PL1 and the rise timing of the second plate signal PL2 coincide. Hence as explained in Fig. 12, coupling noise with the storage nodes of the latch circuit is dispersed or canceled, and so data inversion in the latch circuit due to coupling noise is suppressed.

In the recall operation, the first plate signal PL1 rises first. As a result, due to the above-described principle, a voltage difference is generated between the storage nodes N and NX. In this state, the activation signals EN and ENX are respectively driven to the H level and L level, and the latch circuit 12 is activated. Together with this the voltage difference between the storage node pair is amplified, and the original data is latched.

From this state, by lowering the first plate signal PL1 to L level, polarization states corresponding to the data are generated in the ferroelectric capacitors FC1 and FC2. That is, rewriting to the ferroelectric capacitors FC1 and FC2 is completed. Further, in this waveform example, the second plate signal PL2 is driven to H level, and thereafter is returned to L level. As a result, polarization states corresponding to the data are also generated in the ferroelectric capacitors FC3 and FC4. Hence data is

rewritten to all of the ferroelectric capacitors FC1 to FC4,  
so that even if the power supply falls immediately afterward  
due to some accident, the data would be held in the  
ferroelectric capacitors, and when the power supply was  
5 again turned on, the data could be recalled to the latch  
circuit.

In the waveform example of Fig. 14, the first and  
second plate signals PL1 and PL2 are the same during the  
store operation and recall operation. Hence the  
10 configuration of the circuit to generate these plate signals  
can be made simple. Fig. 15 is a circuit diagram of a plate  
signal generator for the third waveform example. The plate  
signal generator circuit of Fig. 15 is obtained by removing  
the control signal generator circuit 22 and AND gates 26, 27  
15 from the circuit of Fig. 13. That is, the same plate signals  
are generated in the store operation and the recall  
operation, so that circuits relating to these are  
unnecessary. In the circuit example of Fig. 15 also, the  
first and second plate signals PL1 and PL2 have the same  
20 pulse width, and one of the signals is shifted by one pulse  
width.

Fig. 16 is a diagram showing a modified example of a  
nonvolatile latch circuit of this aspect. In this example,  
as described above, the slave latch 12 of the flip-flop  
25 circuit is made nonvolatile. In this circuit, in order to  
balance and make equal the parasitic capacitances of the  
storage node pair N, NX of the slave latch circuit 12, dummy

gates 17D and 18D are added. That is, the transfer gates 17  
and 18 are connected to the node N, and as a result the  
junction capacitances of the CMOS transistor exist as  
parasitic capacitances of the node N. Hence in order to  
5 provide the same parasitic capacitances to the other node NX,  
CMOS transfer gates 17D, 18D which are always in the  
conducting state are provided. By equalizing the parasitic  
capacitances of the storage nodes N and NX, the occurrence  
of data inversion due to coupling noise during store  
10 operations can be suppressed.

Further, in the modified example of Fig. 16, although  
not shown, the shapes of the p-channel and n-channel  
transistors of the pair of inverters 1a, 1b of the slave  
latch circuit 12 are designed such that the current driving  
15 ability of the two transistors is approximately the same.  
That is, for example, the transistor sizes (channel width,  
channel length, and so on), impurity concentrations, and  
other parameters which affect driving ability, are made  
approximately the same. Stated more strictly, if the current  
20 driving abilities of the p-channel transistor of one  
inverter and the n-channel transistor of the other inverter  
are approximately the same, the effect of coupling noise can  
be made approximately the same. Thus if there is no  
imbalance in the current driving abilities of the  
25 transistors of the pair of inverters, the above-described  
data inversion due to coupling at the time of store  
operations can be suppressed.



Fig. 17 is a diagram showing a memory circuit of this embodiment. The nonvolatile latch circuit of this embodiment can be used as a memory cell in a memory circuit. In the memory circuit of Fig. 17, memory cells MC are provided at the positions of intersection of the word line WL and the bit line pairs BL0, BL0X to BL2, BL2X. The memory cell MC has a latch circuit 40, comprising a pair of inverters 1a, 1b; four ferroelectric capacitors FC1 to FC4, connected to the storage nodes N, NX; and transfer transistors 41, 42 connected to the word line WL and bit line pair BL0, BL0X. Activation transistors PT1, NT1 are provided in common for all the memory cell latch circuits 40, and these transistors are driven by the activation signals ENX, EN.

Further, the first plate signal PL1 and second plate signal PL2 are supplied from the plate signal generator circuit 20 to the opposite-side electrodes of the ferroelectric capacitors FC1 to FC4 of each memory cell. These plate signals PL1, PL2 have the same waveforms and timing as in the above-described aspect.

In these memory circuits, while the power supply is turned on, the latch circuits 40 of each memory cell are in the activated state, and operation is similar to that of a normal SRAM. When the power supply is turned off, plate signals PL1, PL2 are generated with shifted timing, and polarization states are generated in the ferroelectric capacitors according to the data at the storage node pairs N, NX of each memory cell. When the power supply is turned on,

after the plate signal PL1 is generated, the latch circuits of the memory cells are activated by the activation signals EN, ENX, and data is restored. Thereafter, the second plate signal PL2 is also driven, and data rewriting is performed.

5           As described above, by means of this aspect, it is possible to prevent data inversion during a data store operation in a nonvolatile data holding circuit using ferroelectric capacitors. Also, rewriting of data to the ferroelectric capacitors can be performed in a recall  
10       operation.

          Further, in the above-described aspect ferroelectric capacitors were provided in the slave latch circuit of a flip-flop to render the circuit nonvolatile; however, ferroelectric capacitors may be similarly provided in the  
15       master latch circuit to render the circuit nonvolatile.

          Thus by means of this invention, in a nonvolatile data storage circuit employing ferroelectric capacitors, operation during data restore operations can be stabilized.